# "Of Course, Data Can Never Fully Represent Reality"

## Assessing the Relationship between "Indigenous Data" and "Indigenous Knowledge," "Traditional Ecological Knowledge," and "Traditional Knowledge"

*Marisa Elena Duarte,[1]* Morgan Vigil-Hayes,[2] Sandra Littletree,[3] and Miranda Belarde-Lewis[3]*

**ABSTRACT**

Multiple terms describe Indigenous peoples' creative expressions, including "Indigenous knowledge" (IK), "traditional ecological knowledge" (TEK), "traditional knowledge" (TK), and increasingly, "Indigenous data" (ID). Variation in terms contributes to disciplinary divides, challenges in organizing and finding prior studies about Indigenous peoples' creative expressions, and intellectually divergent chains of reference. The authors applied a decolonial, digital, feminist, ethics-of-care approach to citation analysis of records about Indigenous peoples knowledge and data, including network analyses of author-generated keywords and research areas, and content analysis of peer-reviewed studies about ID. Results reveal ambiguous uses of the term "Indigenous data"; the influence of ecology and environmental studies in research areas and topics associated with IK, TEK, and TK; and the influence of public administration and governance studies in research areas and topics associated with ID studies. Researchers of ID would benefit from applying a more nuanced and robust vocabulary, one informed by studies of IK, TEK, and TK. Researchers of TEK and TK would benefit from the more people-centered approaches of IK. Researchers and systems designers who work with data sets can practice relational accountability by centering the Indigenous peoples from whom observations are sourced, combining narrative methodologies with computational methods to sustain the holism favored by Indigenous science and the relationality of Indigenous peoples.

Many terms describe Indigenous peoples' creative expressions, including "Indigenous knowledge" (IK), "traditional ecological knowledge" (TEK), "traditional knowledge" (TK), "local knowledge," "Native ways of knowing," and "Native systems of knowledge." A new generation of policy advocates also apply the term "Indigenous data" (ID) to identify "any facts, knowledge, or information about a Native nation and its tribal citizens, lands, resources, cultures, and communities" where data is defined as "information ranging from demographic profiles, to educational attainment rates, maps of sacred lands, songs, and social media activities" (Rainie et al 2017: 1), as well as "information and knowledge about our environments, tribal citizens and community members, and our cultures, communities, and interests" (Rainie et al. 2017: 1). Previous studies identify the challenges caused by a scientific discourse bearing multiple competing signifiers to describe IK (Ngulube and Onyancha 2011; Ocholla and Onyancha 2005; Onyancha et al. 2018; Ramos

[1]Justice and Social Inquiry, School of Social Transformation, Arizona State University, Tempe, Arizona, USA.
[2]School of Informatics, Computing and Cyber Systems, Northern Arizona University, Flagstaff, Arizona, USA.
[3]Information School, University of Washington, Seattle, Washington, USA.

*Correspondence to: Marisa Elena Duarte, School of Social Transformation, Arizona State University, PO Box 876403, Tempe, AZ 85287-6403 USA. E-mail: Marisa.Duarte@asu.edu.

**KEY WORDS:** INDIGENOUS KNOWLEDGE, TRADITIONAL ECOLOGICAL KNOWLEDGE, TRADITIONAL KNOWLEDGE, INDIGENOUS DATA SOVEREIGNTY, INFORMATICS, INFORMATION SCIENCE, DATA SCIENCE.

*Human Biology*, Summer 2019, v. 91, no. 3, pp. 163–178. doi: 10.13110/humanbiology.91.3.03. 

2018). A disparate terminology deepens disciplinary divides and makes peer-reviewed publications difficult to organize and find in research databases. Meanwhile, as Indigenous peoples argue for relationality and holism, the techniques of Western science apply reduction, datafication, and objectification to Indigenous peoples and their biomes (Agrawal 2002). We thus ask the following: (1) How is the term "data" used in the published scientific literature about Indigenous peoples and communities? How do uses of the term "data" relate to established uses of the term "knowledge" as defined in the literature about Indigenous peoples and communities? What patterns and trends are associated with these uses? (2) Is there observable disciplinary divergence in usage of the terms "data" and "knowledge" and in patterns and trends associated with such usage?

Through a decolonial, digital, feminist, ethics-of-care approach to topical analysis of records about Indigenous peoples knowledge and data—including network analyses of author-generated keywords, associated noun phrases, and associated research areas—and content analysis of peer-reviewed studies about ID, we reveal patterns and trends shaping definitions of IK and ID across research domains. Social graphs show patterns in the convergences and divergences of associated research topics and areas. We interpret results as domain experts and contextualize the limitations of ID work and IK work.

## Literature Review

IK is a scientific construct and, as such, depends on a scientific definition of data. As a construct, data is designed to be constantly transformed toward increasing clarity around a line of inquiry. Any single observation is a datum, and once synthesized into a decodable string of meaning, data becomes information, indicating an increasing level of mathematical and qualitative complexity. Once parsed, valued, and legitimized, information becomes knowledge and is most recognizable in its marketable forms as intellectual property. Metadata maintains this life cycle of information; its purpose is to transmit information. This characterization of the relationships among data, information, knowledge, and metadata is best known as the data-information-knowledge model and is integral to the theory and practice of information science (Liew 2007; Zins 2007). The data-information-knowledge model reveals the role of institutions, computing, and individuals in transforming data sets toward increasing degrees of complexity.

Data sets have become ubiquitous in our society. The FBI uses them to track criminal behaviors and suspects. Stockbrokers, advertisers, and entrepreneurs use them to boost sales. Social media platforms gain revenue by selling users' "data doubles." Governments and private corporations invest in information and communication technologies to transmit signals. Fields of study, including genetics, epidemiology, social media studies, machine learning, and artificial intelligence, rely on the pervasiveness of data sets for computational methodologies, including data sets created by, for, and about Indigenous peoples.

Prior to the rise of big data, Indigenous thinkers have interrogated biocolonialism, the technoscientific habit of categorizing Indigenous ways of relating and being as items, documents, artifacts, relics, or products—kinds of intellectual property—that abet capitalist erasure of Indigenous life (Harry and Kanehe 2006; Harry 2011; UN Environmental Programme 1997). More recently, Indigenous researchers assert Indigenous peoples' rights to own, access, and regulate data sets made about them, arguing that Indigenous peoples have an inherently datafied way of being (Carroll et al. 2019). This is a paradigmatic shift from previous arguments that establish Indigenous ways of being as holistic and relational rather than categorical (Archibald et al. 2008; Cajete 2000; Littletree 2019; Meyer 2008; Smith 2012; Wilson 2008). In 2015, a group of Indigenous scholars convened in Australia to discuss ID sovereignty, "the legal and ethical dimensions around data storage, ownership, access and consent, to intellectual property rights and practical considerations about how data are used in the context of research, policy, and practice" (Kukutai and Taylor 2016: 2). Their contributions reflect the experience of Indigenous peoples confronting the technocratic habitus of the English-speaking, technologically advanced countries—Canada, Australia, New Zealand, and the United States—where the knowledge theory of value has created a market for all kinds of information packaged and repurposed as data.

Understanding Indigenous peoples' historical relationships with the life cycle of information suggests a close relationship between intellectual practices of science and technology and Indigenous peoples' tactics for navigating technoscientific industries and institutions. It indicates the continuing malleability of data, in particular when Indigenous peoples interpret "data," "information," and "knowledge" across technical, political, practical, epistemic, and ontological domains. Indigenous information scientists are keenly aware of the practical implications of these terms (Lee 2011; Nakata et al. 2005). Ngulube and Onyancha (2011) identify the inadequacy of indexing and retrieval tools for IK. Onyancha et al. (2018: 157) attributes this structural inadequacy to "Western rooted knowledge organisation systems [that] do not embrace the contextual, dynamic, holistic and harmonious nature of indigenous knowledge such that often the used terms or information used to describe it compromises it to the extent of the loss of its uniqueness among others." Researchers who utilize these systems to search for and learn about IK find that they are unable to comprehend the depth of Indigenous peoples' lived reality because the systems decontextualize Indigenous relationality. This is particularly challenging because research databases are an integral means to trace accounts of Indigeneity (Cooper et al. 2019).

## Materials and Methods

We are a team of four Indigenous information and computer scientists, each with over 15 years of professional and scholarly experience. We conducted this research in accord with a feminist ethics of care, that is, a reliance on our situated knowledge to interpret the systematic and structural impact of colonizing knowledges in which critical analyses of "different kinds of data—implicated at different registers of engagement over time—can 'turn' us in practical ways to critically rethink the ongoing intersectional networks of relations, values, and ethical commitments that undergird our research and those of others" (Luka and Millette 2018: 4; see also Gilligan 1982; Haraway 1988; Tuhiwai Smith 2012). Unlike retributive justice theories, Gilligan's (1982) formulation of a feminist ethics of care is relational: in order to gather the most relevant information undergirding an unjust scenario, one must immerse and locate oneself in it and then discern the nature of the relationships among relevant actors and issues to ascertain corrective responsibility. Our approach is thus inductive and iterative, with our methods functioning like a multilensed probe, sensing and revealing traces of bodies of literature.

### Phase I: Framing Indigenous Information Scientific Constructs of Data and Knowledge

For over a century, scholars have written about the facets of IK (Berman 1971; Hajibayova and Buente 2017; Lilley 2015; Littletree and Metoyer 2015; Moorcroft and Garwood 1997; Szekely 1997). Indigenous approaches to data represent a recent area of investigation and include critiques of scientific misuses of data sets and the need for tribal research review processes, uses of consumer genetic testing to make claims to Native American ancestry, studies of digital infrastructures and systems, surveillance studies, decolonial approaches to computational methods, and studies of tribal data governance (Tallbear 2013; Liboiron 2015; Murphy 2014; Vigil-Hayes et al. 2017; Marley 2019; Duarte 2017; Pulley 2014; Walter and Andersen 2013; Tsosie 2019). For this study, we reviewed the publications of Indigenous scholars who specifically define and operationalize the term "data" in the broader context of their work, and then developed a framework identifying facets of the term used in projects relating to Indigenous peoples (Table 1, first three columns). Through this method, we conceptualized how Indigenous and decolonial scholars discursively use the term to signify methodological processes and social and technical phenomena.

### Phase II: Curating Sources from WoS for Qualitative and Quantitative Analysis

To get a sense of how our terms appear in the published scientific literature, we searched the Web of Science (WoS) Core Collection for records on the topics of Indigenous data, Indigenous knowledge, traditional knowledge, and traditional ecological knowledge. We recognize the limitations of using the WoS for citation analysis of an Indigenous subject, in that it reflects a Western representation of IK and does not index sources integral to Native American and Indigenous studies. Nevertheless,

**Table 1. Facets of Data and Characteristic Features as Noted by Indigenous and Decolonial Scholars**

| Facet of Data | Definition | Indigenous and Decolonial Scholars | Terms That Included "Data"[a] |
|---|---|---|---|
| Data as object | A set of scientific observations, plural for "datum," shorthand for "data sets" | Walter and Andersen 2013 | data items; local data |
| Data as property | A set of information that an authorized community of users recognizes as IK, TK, TEK; proprietary, commensurate with intellectual property and private property claims | Harry and Kanehe 2006; Dei 2000; Marley 2019; Kukutai and Taylor 2016 | data sources; data collection dependency (on local knowledge); decolonized Indigenous data framework; data analysis dependency (on local knowledge); data interpretation dependency (on tribal participation); Indigenous data identifiers; data ownership; data stewardship; Indigenous data jurisdiction; data protocols; local data; data usefulness (for Indigenous communities); administrative data |
| Data as structural element | A part of a cycle of increasing complexity tending toward the construction and circulation of information, the coconstruction of knowledge, and the emergence of metadata | Shannon and Weaver 1963[b] | data quality; data consistency; data integrity; data accuracy; data aggregation/disaggregation; culturally-informed data quality framework; decolonized Indigenous data framework; data analysis dependency (on local knowledge); data interpretation dependency (on tribal participation); local data; historical data; modern data; accessible sources of data |
| Data as research | A field of study: data science, Indigenous data science, Indigenous informatics | Dei 2000; Ngulube and Onyancha 2011; Onyancha et al. 2018 | None found |
| Data as way of knowing | A haptic, sensory, or phenomenological relationship with data, i.e., Indigenous design experience of video gaming, coding, augmented reality, Indigenous user experience | LaPensée 2017; Pulley 2014 | None found |
| Data as technology | A feature of a technoscientific industry, a social construct of a particular era and assemblage of actors | Duarte 2017; Murphy 2014 | None found |
| Data as historical condition | A shorthand for a particular historical and ideological moment; "Big Data" | Duarte 2017; Carlson 2019 | historical data; modern data |
| Data as infrastructure | An integral feature in the material structure of telecommunications devices, i.e., "data plan" | Duarte 2017 | None found |
| Data as surveillance | The discrete parts of human intelligence and signals intelligence labor, tending toward the construction of actionable information by governments or organizations | Browne 2015; Noble 2018 | data sources; data availability; data accessibility; data collection dependency (on local knowledge); data collection frameworks; culturally-informed data quality framework; decolonized Indigenous data framework; data interpretation dependency (on tribal participation); Indigenous data identifiers; Indigenous data jurisdiction; local data; data usefulness (for Indigenous communities); data risks; historical data; modern data; administrative data; data regime |
| Data as process of analysis | A methodological approach, such as a data set or a process of datafication needed to conduct Indigenous network analysis or Indigenous statistical analysis | Walter and Andersen 2013; Vigil-Hayes et al. 2017 | benchmark data; data consistency; data accuracy; data definitions; data comparability; data collection frameworks; culturally-informed data quality framework; decolonized Indigenous data framework; data analysis dependency; data interpretation dependency; Indigenous data identifier; local data; data gaps |
| Data as story | A crafting of narratives of the world through data | Pulley 2014 | None found |
| Data as kinship | A mapping of ways we relate to one another; genetic information; genealogy | Tallbear 2013 | None found |
| Data as subject | The data in itself tells us something beyond its use as an object of manipulation; meta-analysis of data types, data sets, and information | Doyle 2013; Liboiron 2015; Nakata 2007 | None found |

[a] As identified in 17 WoS articles.
[b] The authors would like to note that these are non-Indigenous and nondecolonial scholars whose work is integral to the fields of computer science, library and information science, informatics, data science, and computational methodologies.

the WoS has been used extensively in previous studies involving quantitative citation analysis and is recognized as an essential academic research database, containing over 20,000 peer-reviewed scholarly journals across the life sciences, biomedical sciences, engineering, social sciences, arts, and humanities. The WoS has robust citation analysis capabilities, particularly the Analyze Results feature, which we used to identify trends in subject categories, research areas, and journal titles. We considered other citation analysis tools, such as Google Scholar, but these do not have a formal application program interface and block Web-scraping tools, resulting in incomplete data sets.

Two members of the research team independently searched the WoS Core Collection using the "topic" search field, which includes author-generated keywords, abstracts, titles, and Keywords Plus. The author-generated keywords field is populated by words that authors of articles choose to describe the content of their articles. The Keywords Plus field is populated by a WoS algorithm that

identifies noun phrases that frequently occur in each article's bibliography. The WoS Core Collection does not use a controlled vocabulary except for institutional names. We discussed our results with regard to the number of records per search, trends in journal titles, topical coverage, and associated fields. Three of the data sets (TEK, TK, IK) yielded thousands of records for each search and provided a sufficient number of records for quantitative network analysis. Because ID yielded substantially fewer records (26 total records were found), we decided to instead conduct a content analysis of selected articles from that set of records, which later helped us discern patterns between uses of the terms "data" and "knowledge" (see Table 2).

**Table 2. Overview of Data Sets Used for Quantitative Network Analysis**

| Term | Number | | | | |
|---|---|---|---|---|---|
| | Articles | Authors | Journals | Affiliations | Topics |
| "Indigenous data" | 26 | 128 | 26 | 28 | 25 |
| "Indigenous knowledge" | 3,420 | 7,930 | 1,310 | 3,263 | 113 |
| "Traditional knowledge" | 3,860 | 10,387 | 1,570 | 3,711 | 131 |
| "Traditional ecological knowledge" | 1,159 | 3,252 | 384 | 1,128 | 71 |

### Phase III: Modeling Networks of Terms, Research Areas, and Keywords

Using statistical and network analyses, we created charts, models, and visualizations to inform our interpretation of results produced through the qualitative content analysis of articles about Indigenous data, as well as our interpretation of overall findings. To begin, we wrote a script to collect specific sets of records from the WoS through its application program interface. We collected records containing the query terms "traditional ecological knowledge," "traditional knowledge," "Indigenous knowledge," and "Indigenous data," because these were found in the author-generated keyword, abstract, and title fields of WoS records. This resulted in a total of 8,470 records (detailed in Table 2). We applied statistical and social network analyses to identify patterns in the uses of "traditional ecological knowledge," "traditional knowledge," "Indigenous knowledge," and "Indigenous data" in records obtained from the WoS Core Collection, including a measure of topical overlap, measures of co-occurrence of terms, and a measure of similarity (Jaccard similarity [JS]) of uses of terms across fields. To analyze the topics that researchers related to ID, IK, TK, and TEK, we quantified author-generated keywords that co-occurred with noun phrases that appeared in article abstracts and identified the top 10 noun phrases in records matching our query terms.

To quantify the extent of topical overlap among data sets garnered through each query, we calculated the Jaccard coefficient for each data set, that is, the ratio of records that contained one of the query terms as an author-generated keyword over the sum of records that resulted from each query. We further quantified the overlap between the areas of research captured by our queries by calculating the JS between query terms used in each of the data sets. We then applied the JS to construct relational networks in Gephi, an open-source graph visualization software, based on the co-occurrence of several features of the data sets, including author-generated keywords, noun phrases in the abstract, and related areas of research. Specifically, the JS aids in the construction of the distance—or length of the links—between nodes in our relational networks, with the nodes indicating, alternatively, frequency of noun phrases and areas of research associated with author-generated keywords.

To model how the query terms use different keywords to refer to different topics (as inferred by noun phrases used in the abstract) in our data sets, we constructed a bipartite network using two disjoint sets of nodes: (1) noun phrases used in the abstract and (2) author-generated keywords. A link exists between a keyword and a noun phrase if they co-occur in the same article. We then used the Python NetworkX package to create a projection on the keyword nodes by calculating the JS between the sets of noun phrases associated with each pair of keywords: the more similar the keywords, the more heavily weighted the link between them. We then used the Louvain method for community detection to separate the keywords into classes by maximizing the number of connections between nodes within a class rather than between nodes of different classes, which with the aid of Gephi resulted in a visualization of statistically significant communities of nodes (Blondel et al. 2008). We then used Gephi's palette to color code nodes according to their class labels, resulting in explorable social graphs for each data set. In addition, we calculated the betweenness centrality for

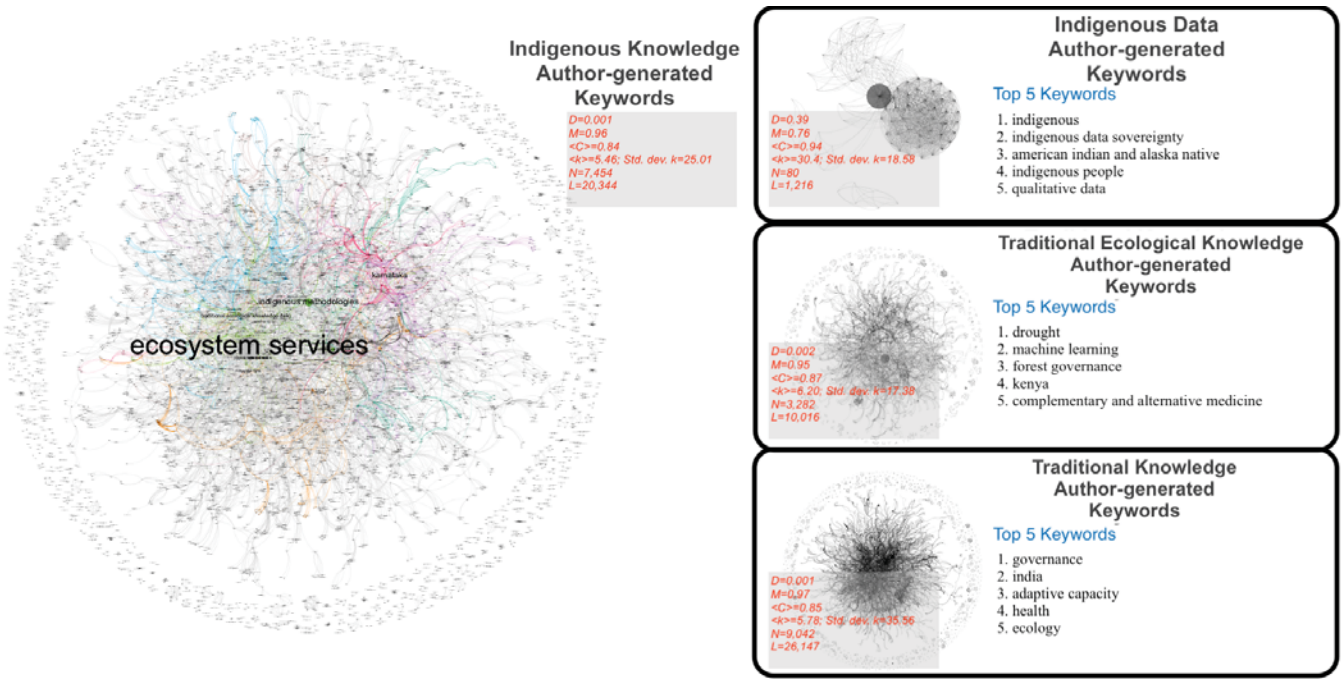



**FIGURE 1.** Author-generated keywords in records containing "Indigenous data" (ID), "Indigenous knowledge" (IK), "traditional ecological knowledge" (TEK), and "traditional knowledge" (TK). The graphs for IK, TK, and TEK reveal densely clustered centers surrounded by an array of smaller, disconnected satellites of keyword clusters, indicating cohesion in the topics comprising the central body of literature about IK, TK, and TEK orbited by a loosely associated set of topics influenced by environmental studies. For IK, top five keywords are "ecosystem services," "Indigenous methodologies," "karnataka," "traditional ecological knowledge," and "Indigenous studies." For ID, the largest node forms around the keyword "Indigenous." The high betweenness associated with "Indigenous" and its position as a bridge between nodes from different classes demonstrate its role in connecting what might be disparate topics. We report basic statistics for each network in gray boxes: density (*D*), average clustering coefficient (<*C*>), modularity (*M*), average degree (<*k*>) and standard deviation of degree, number of nodes (*N*), and number of links (*L*).

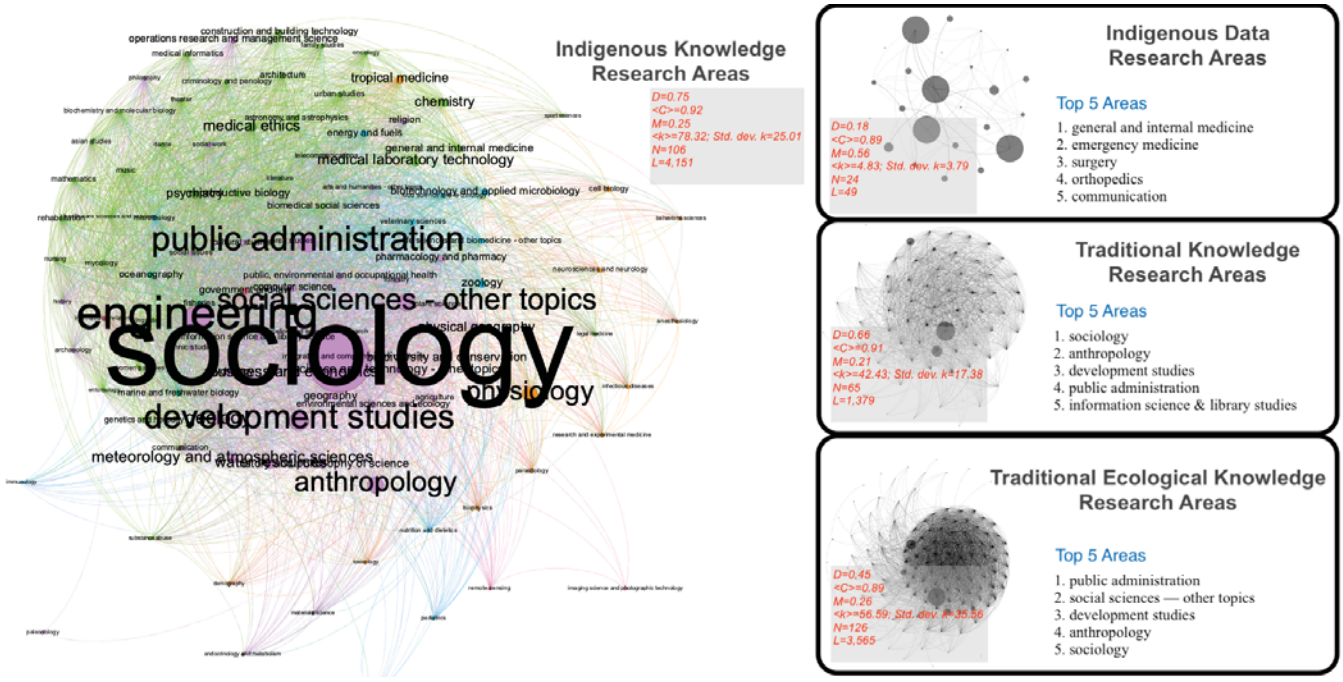



**FIGURE 2.** Top research areas that emerged in the bipartite network model between the selected topics (ID, IK, TK, and TEK) and affiliated research areas. IK, TK, and TEK have a well-defined core of research areas, with IK demonstrating tight integration between such topics as sociology, medicine, public administration, and engineering. For IK, top research areas are sociology, engineering, development studies, public administration, and social sciences – other disciplines. Conversely, ID has relatively few affiliated research areas, most of which focus on medicine. Top keywords and node sizes were determined using the PageRank algorithm. We report basic statistics for each network in gray boxes: density (*D*), average clustering coefficient (<*C*>), modularity (*M*), average degree (<*k*>) and standard deviation of degree, number of nodes (*N*), and number of links (*L*).

each node, which represents the probability that a node lies on the shortest path between any pair of nodes in the network. Keywords with a high betweenness centrality are often used alongside a variety of other keywords. Because Gephi is a tool for exploring social graphs, we could run our cursor over the visualizations in Gephi to gain more detail about certain substructures within the larger network structures, including specific node features such as associated noun phrases and research areas. Exploring our graphs (Figures 1 and 2) as a team helped us characterize, narrativize, and prioritize observable and measurable patterns in our data sets. When creating images of the graphs, we used the PageRank algorithm to make nodes with a higher levels of connectivity appear larger (Page et al. 1998).

### Phase IV: Characterizing Uses of "Data" through Content Analysis

Three members of the research team independently reviewed 17 of the 26 total articles that contained the phrase "Indigenous data" and that claimed to be about Indigenous data with a focus on research about Indigenous issues in North America. We cocreated a list of uses of the term "data" as they appeared across this data set and noted relevant fragments such as phrases, sentences, institutional affiliations, methodologies, and value statements. We discussed our findings as a group and fitted these into the framework identifying facets of "data" (Table 1). This helped us discern features shaping the ontological relationship between uses of the term "data" and uses of the term "knowledge" as defined in the literature about Indigenous peoples.

### Phase V: Interpretive Comparison of Qualitative and Quantitative Approaches

Finally, we compared the results of overall quantitative analyses with qualitative content analysis of uses of the term "Indigenous data." We interpreted results in light of relationality as an Indigenous way of knowing, as well as domain knowledge in the fields of information science and computer science.

## Results

We cycled through the phases of our methods iteratively, continually shaping and refining our results, as we isolated the most significant findings with regard to our research questions. The results of our analyses are therefore presented in the order of their statistical significance and most impactful qualitative meaning.

### The Term "Data" Is Used Ambiguously and Inconsistently

With regard to Indigenous peoples, the term "data" is used ambiguously and inconsistently in the published scientific literature. Qualitative review of 17 peer reviewed research papers about Indigenous data reveal that "data," "information," and "knowledge" are used interchangeably. "Data" is often conflated in meaning and can refer to objects such as data sets, processes such as communication flows, and historical conditions. It is used in relationship to the concept of sovereignty, but without contextualizing how it relates to specific governance processes, in the case of legal and political sovereignty, or relationality, in the case of inherent sovereignty.

Content analysis of the term "data" throughout the 17 articles reveals at least 29 distinct and nuanced uses of the term, which are detailed in the last column of Table 1. When we fitted the uses of the term "data" from the 17 articles with the facets of data and characteristic features noted by Indigenous and decolonial scholars, many of the terms relate to six facets of data (Table 1). Data-as-object uses signify the isolation of observations into malleable objects intended for further scientific analysis. Data-as-property uses signify a piece of property that pertains to, is sourced from, or originates from a polity, whether an Indigenous people or a nation-state government, and that requires the context to be precisely and accurately deciphered. Data-as-structural-element uses signify the cyclical complexification of message and meaning, leading to the crystallization of knowledge. Data-as-historical-condition uses signify social, historical, and political conditions. Data-as-surveillance uses signify the acquisition and preparation of observations through the use of informants or other intermediaries for the purpose of creating context-specific frameworks to aid in governmental tracking. Data-as-process-of-analysis uses signify statistical and social scientific methods to manipulate data sets for the purpose of answering research questions. We also note that none of

the 17 articles use the term "data" as characterized by eight of the facets of data in our framework: data as research, data as a way of knowing, data as technology, data as infrastructure, data as story, data as kinship, and data as subject.

Content analysis reveals that the term "data" is often used to refer to data sets and that the field of demography strongly influences usage of the phrase "Indigenous data." "Data" is often qualified, making it a signifier for a process rather than an object. It is also not uncommon to find sentences that use the term multiple times to signify different meanings, such as in the following: "Another important element of the data regime is to recognise that 'data' is both qualitative and quantitative and both must be considered valid and equally important data sources" (Wilks et al. 2018: 11).

Content analysis of articles about Indigenous data also reveals infrequent citation of the scholarly literature on American Indian sovereignty and almost no citation of scholars of IK or Native ways of knowing.

### "Indigenous Data" Is a Relatively New Construct

"Indigenous data" is a relatively new construct designed to support informed governance of Indigenous peoples. Content analysis also revealed a range of social values about the construct of "data." There appeared to be an assumption that data sets preexist and need only to be gathered by an Indigenous informant. The assumption is that, once gathered, the data sets can be fitted into a kind of framework that a government or nongovernmental organization can apply to determine factors shaping the lives of Indigenous peoples at scale, resulting in better "data outcomes." There are assumptions that ID helps national governments assess services for resident Indigenous peoples, allowing Indigenous peoples to "speak back" to the state with statistical evidence. There are assumptions that ID is a counter to the colonizing and deficit-based narratives that further marginalize Indigenous people (Walter and Andersen 2013; Wilks et al. 2018). There are assumptions that national governments and supranational organizations need ID to guide decision making and inform policy and that supranational organizations such as the World Health Organization and the United Nations best establish indicators of well-being. On the other hand, there were also strong statements about how Indigenous people distrust data collection due to Western scientific practices of extraction.

In sum, qualitative analysis reveals that "Indigenous data" is a euphemism for national demographic measures about resident Indigenous populations as comparable to existing demographic measures about resident non-Indigenous populations (Abu-Saad 2016; Anderson et al 2016; Davis et al. 2009; Liebler 2018). We also noted that "Indigenous data" is most often used to describe data that has been collected *about* a population rather than data that has been collected through the application of Indigenous research methodologies.

### Use of "Data" and "Knowledge" Varies by Discipline and Field

With regard to Indigenous peoples, uses of the terms "data" and "knowledge" are strongly influenced by differences in disciplines and fields, with ecology and environmental studies relying on the term "knowledge." "Indigenous knowledge" and "traditional knowledge" function as a paradigmatic boundary spanners, allowing for convergences across disparate research areas.

Qualitative review of records based on queries in WoS revealed that "traditional knowledge" (3,266), "Indigenous knowledge" (2,907), and "traditional ecological knowledge" (453) appeared in abstracts and titles at far greater rates than "Indigenous data" (52). Table 3 shows the top five journals retrieved from WoS queries on the topics of TEK, IK, TK, and ID. "Traditional knowledge," "Indigenous knowledge," and "traditional ecological knowledge" appeared far more in titles associated with biology, environmental studies, ecology, ethnobotany, and pharmacy studies; further qualitative review of the titles and abstracts shows the influence of economic development, capitalist enterprise, and modernization studies associated with these terms. "Indigenous data" appears to be a term emerging in titles associated with policy and governance, with titles and abstracts reflecting association with the fields of public administration and governance.

Review of the top author-generated keywords co-occurring with "traditional knowledge," "Indigenous knowledge," and "traditional ecological knowledge" reveals the influence of ethnobotany and sustainability sciences, whereas the top

**Table 3. Top Five Journals Retrieved from WoS Queries for Each Term**

| Journals Retrieved | Percentage of Total Record |
|---|---|
| "Traditional ecological knowledge" (453 records) | |
| Ecology and Society | 11.5% |
| Human Ecology | 5.5% |
| Journal of Ethnobiology and Ethnomedicine | 3.4% |
| Arctic | 2.8% |
| Ecological Applications | 2.8% |
| "Indigenous knowledge" (2,907 records) | |
| Indian Journal of Traditional Knowledge | 4.6% |
| Journal of Ethnobiology and Ethnomedicine | 3.3% |
| Journal of Ethnopharmacology | 3.2% |
| Ecology and Society | 2.1% |
| Human Ecology | 1.8% |
| "Traditional knowledge" (3,266 records) | |
| Indian Journal of Traditional Knowledge | 7.4% |
| Journal of Ethnopharmacology | 7.3% |
| Journal of Ethnobiology and Ethnomedicine | 6.3% |
| Economic Botany | 1.8% |
| Arctic | 1.6% |
| "Indigenous data" (52 records) | |
| Lancet | 2.7% |
| Aboriginal Policy Studies | 3.9% |
| Agroforestry Systems | 3.9% |
| American Behavioral Scientist | 3.9% |
| American Journal of Public Health | 3.9% |

keywords co-occurring with "Indigenous data" reveals the influence of public policy studies and quantitative social science (Figure 3, Supplementary Figures S1–S3). For all query terms except "Indigenous data," the query term was also the top author-generated keyword. We observed differences in topical focus as well, with IK, TK, and TEK associated more often with issues such as climate change, conservation, and biodiversity, and ID associated more with public administration.

We observed significant overlap with respect to our query terms matching up with the top author-generated keywords associated with each of the records. To get a better sense of how authors might be using these terms in a more intentional manner, and to remain consistent with our iterative method of analysis, we further filtered records in each data set to include only records that include the query term in the author-generated keywords. This reduces the ID data set to 2 entries, the IK data set to 1,067 entries, the TK data set to 941 entries, and the TEK data set to 417 entries. That the ID data

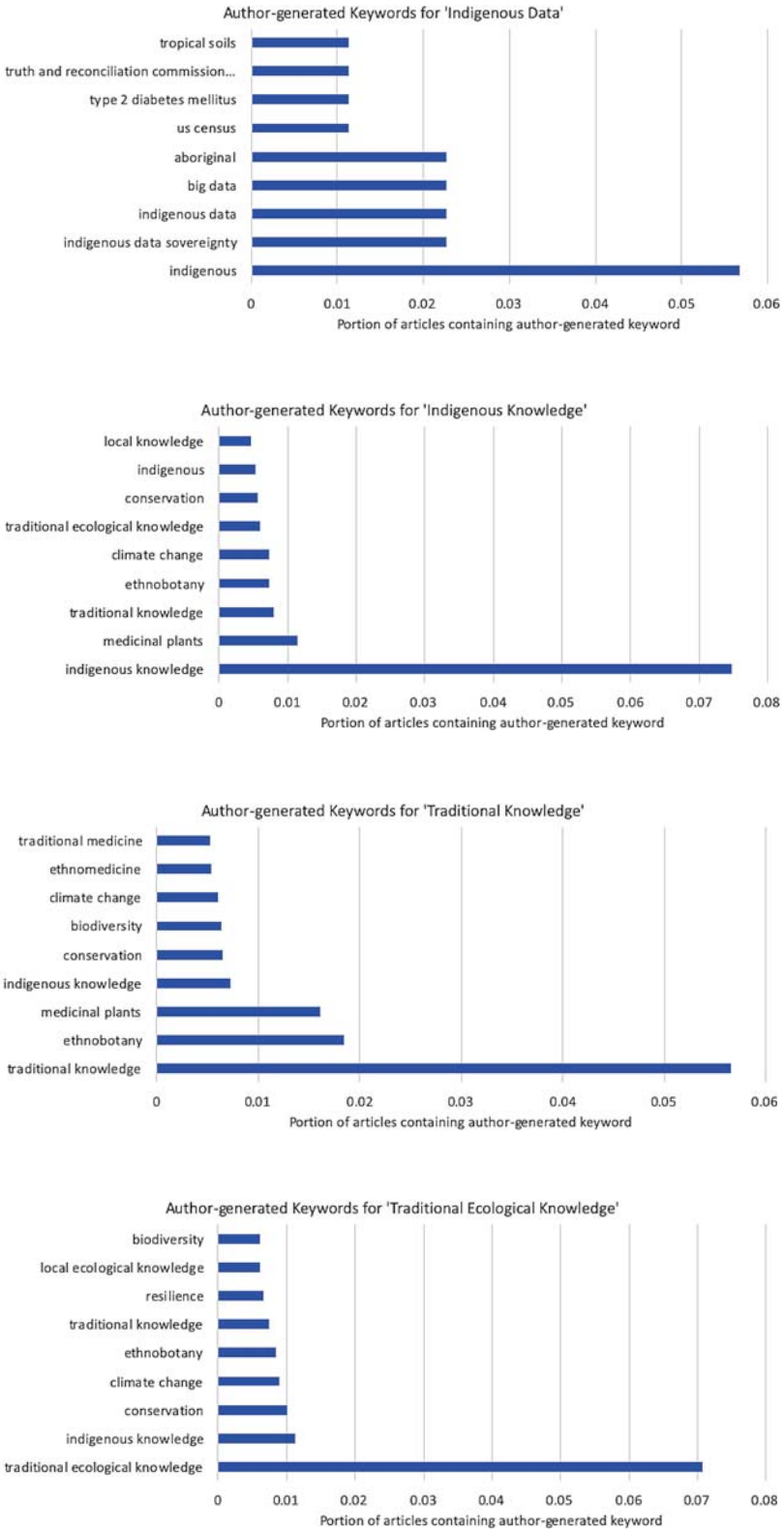



**FIGURE 3.** Top nine co-occurring keywords associated with records that matched each of our search terms.

set is reduced so dramatically points to the relative novelty of the term.

To further quantify the extent of topical overlap, we calculated the portion of records that contained any of our query terms in the body of the article record and that also contained one of the query terms as an author-generated keyword (Figure 1). While our calculation shows that the most frequent keyword–query term coincidence occurs when the query term matches the author-generated keyword, we also note significant overlap between "traditional knowledge," "Indigenous knowledge," and "traditional ecological knowledge," with very little coincidence between "Indigenous data" and any of the other query terms, indicating the relative isolation of the term in the broader literature. Figure 1 depicts side-by-side comparisons of the structural differences among social graphs comprising author-generated keywords associated with "Indigenous data" (80), "traditional ecological knowledge" (3,313), "Indigenous knowledge" (7,556), and "traditional knowledge" (9,154).

Figure 1 also represents the author-generated keywords in the records associated with "Indigenous data"' as well as the top five keywords associated with the search. For the "Indigenous data" data set, emphasis on the word "Indigenous" contrasts significantly with the other data sets, which emphasize such issues as climate change, environmental governance, and health (Figure 1). The "Indigenous data" data set also emphasizes populations of Indigenous human beings more than the other data sets (Supplementary Figure S1). Unlike the "Indigenous knowledge" data set, the data set of author-generated keywords in the records associated with "traditional ecological knowledge" is less densely clustered, although betweenness is more evenly dispersed among topics that comprise the TEK body of literature (Supplementary Figure S2). Interestingly, "Indigenous knowledge" did not appear with much influence, though "traditional ecological knowledge" did appear in the "Indigenous knowledge" data set (Figure 1). This indicates topical difference in the terms "Indigenous knowledge" and "traditional ecological knowledge," where the latter has less overlap with Indigenous methodologies and Indigenous studies and more overlap with matters of governance.

The structure of the graph representing the author-generated keywords associated with "traditional knowledge" is similar to the structure of the graph associated with "traditional ecological knowledge," indicating similar degree of cohesion and integration of satellite topics (Figure 1). Similar to the "traditional ecological knowledge" graph, the "traditional knowledge" graph centers on climate issues but is noticeably lacking in reference to issues of governance (Supplementary Figure S3).

We also used the bipartite network methodology to examine how different research areas use similar author-generated keyword groupings (Figure 2). By visually and collectively comparing the networks for each data set, we were able to identify critical differences in the research areas that tend to use the query terms, and how research areas cluster together based on how closely their keywords align. In these networks, nodes represent research areas that have significant overlap in author-generated keywords.

The ID research areas form separate groupings, with no overlap between the distinct research areas (Figure 2, Supplementary Figure S4), which perhaps indicates the newness of the term: no one field or discipline represents a sizable amount of records using the term, and various fields and disciplines have not yet had time to collaborate around the ID research area. The earliest article related to ID is Davis et al. (2009), with the bulk of scholarship published in 2015 and later. We examined the top research areas that emerged in the bipartite network projection between the topic of IK and affiliated research areas (the largest image in Figure 2). Several clusters are discernable; the top five are sociology, engineering, development studies, public administration, and social sciences – other disciplines, and smaller clusters are distributed across a range of research areas, including microbiology, women's studies, physical geography, and demography. This indicates the relevance of IK as a paradigm—a way of seeing phenomena about the known universe—rather than as a discrete subject or discipline, and also indicates the boundary-spanning function of studies of IK, as the topic stimulates unexpected convergences across otherwise divergent disciplines.

Comparatively, the research areas affiliated with the TEK data set are dispersed across fewer fields and disciplines. Supplementary Figure S5 shows that the research areas affiliated with TEK are largely shaped by environmental studies in

combination with social sciences such as anthropology and sociology. The network model of research areas affiliated with the TEK data set reveals the relative influence of the fields of sociology, anthropology, and development studies.

Interestingly, the network model showing research areas affiliated with TK (Supplementary Figure S6), again, is more similar to the network model of research areas affiliated with IK, with a densely clustered core of research areas. Similar to the IK model, the topic of TK appears to function as a boundary spanner, with a wide range of research areas applying TK, from biotechnology to behavioral science and zoology. Unlike the records gathered through the IK query, the records gathered from the TK query are not necessarily about Indigenous peoples or their creative expressions but, rather, signify a kind of knowledge either that is not yet automated or technicized or that, due to its process of manifesting, is dependent on preindustrial, pretechnological, or nonindustrial/nontechnological ways of life. It is thus not surprising to see public administration and development studies in the highly ranked TK research areas, as the pursuit of many nation-states in the technologically advancing countries is to "modernize" the preindustrial ways of life of its denizens. Similar to the TEK research areas, TK is shaped by environmental studies, though not to the same degree, as the network model reveals the relatively stronger pervasiveness of social science in the literature.

In sum, these results reveal the interplay of literature on the topics of IK, TEK, and TK, with the relatively new subfield of ID emerging through the increasing availability of statistically significant data sets about Indigenous peoples and occurring alongside larger, more cohesive bodies of literature about the relationship between environmental changes and human ways of knowing, Indigenous ways of knowing, and nonindustrial ways of knowing. The thread of industrialization, governance, and development theory winds through the entire corpus of records.

## Discussion

In their application of a feminist ethics of care to the study of big data, Luka and Millette (2018: 2) assert that "data can never fully represent reality, although data analyses provide pathways to help understand the world within which we live." In this investigation, we discerned scholarly uses of the term "data" with regard to Indigenous peoples and then depicted those findings against the backdrop of much larger bodies of literature on the topic of knowledge in Indigenous contexts. Our analyses reveal how researchers evoke nebulous uses of the word "data" to fit the conventions of their respective fields of study and the needs of their research projects, especially as it pertains to the measurement and surveillance of Indigenous populations. "Biocolonialism" appears in the literature around "traditional knowledge," "Indigenous knowledge," and "traditional ecological knowledge" as author-generated keywords referencing the extraction of natural resources and methods from Indigenous peoples while Indigenous peoples continue to experience displacement and dispossession due to industrialization, climate change, and economic wars. As such, we suggest that even the most comprehensive data sets cannot represent the complex realities of Indigenous peoples; instead, they represent the questions that researchers ask.

Researchers of ID may benefit from additional grounding in the IK and TEK bodies of literature, as these relate to environmental change and as ID bears more of a focus on the governance of Indigenous populations. Researchers of IK would also benefit from examining the cocreation and management of TK by non-Indigenous populations, in particular with regard to the outcomes of development theory and the treatment of biomes. Similarly, researchers of TK and TEK would benefit from investigating how Indigenous sovereignty movements pursue rights and ownership of knowledge as property and data as property, as well as claims to privacy, security, and ownership of knowledge as process and data as process. Proponents of ID sovereignty would also benefit from applying a more nuanced vocabulary, one that effectively places the ID sovereignty movement into conversation with the discourse and policies that already shape the IK and TK paradigms, especially regarding intellectual property practice and law. A refined vocabulary would also allow the ID sovereignty movement to become more ontologically robust, contributing to the epistemic stakes of Indigenous science, a paradigm that redefines how we think we know the universe around us, especially as we find

ourselves in landscapes shaped by climate change, industrialization, and technicization.

## Perspectives

One aspect of Indigenous science that is not revealed through our methodological lens is that of relationality. According to relationality, all phenomena can be investigated through consideration and thick description of the relationships that form the ecology of belonging around all objects, ideas, and beings (Wilson 2008). Through Indigenous methodologies, we are accountable to the relationships we make as we ask questions on behalf of, collect observations from, and disseminate knowledge about Indigenous communities. Accordingly, Tsosie's (2019) conclusions regarding "tribal data" indicate the importance of practicing cultural sovereignty as we make plans for protecting our land, resources, and culture for the benefit of the seventh generation.

That "drought" is the most prominent author-generated keyword in the TEK data set offers an unexpected insight (Figure 1). More than a node in a graph, the keyword "drought" represents thousands of hours of research, millions of dollars in grant funding, and many researchers working through their institutions to solve the world's water crisis through the application of TEK. When it comes to wicked problems like climate change, environmental damage, and disproportionate numbers of missing and murdered Indigenous women, we cannot expect data sets alone to generate solutions. We need conscientious deliberation with individuals and groups from the most affected communities.

Relationality demands accountability and responsiveness. For a system designer or researcher working with data sets, this would mean being accountable to the communities and landscapes from which observations were acquired. Scientists, information professionals, and programmers need to humanize their processes, creating relationships to discern reality rather than depicting reality through rendering the trace evidence. Advocates of "Indigenous data" in particular would benefit from Indigenous approaches to library and information management, where care is taken to consider the relationality embedded in creating, storing, using, protecting, and preserving the creative expressions of Indigenous peoples, particularly as these expressions move from our families and communities into institutions through various formats (Christen 2015; Christen and Anderson 2019; Lawson 2004; Littletree 2019; O'Neal 2015).

Methodologically, to avoid reductivism, such an approach means combining narrative techniques, such as story work, with statistical and computational methods and practicing a critical, reflexive approach to the silver-bullet ethos shaping solutions informed by access to large data sets.

Still, in its very malleability, data as structural element offers scientists hope in the form of empirical evidence; there is persuasive power in the data set. A sophisticated understanding of the semantic and ontological relationships among data, information, and knowledge as these emerge in the context of Indigeneity will likely produce new conceptual frameworks, methodologies, and metatheory. Next steps include tracing the theoretical collaborations of scholars who work with data and knowledge for the advancement of Indigenous peoples and biomes. Investigating their trajectories could shine a light on their reasons for pursuing certain constructs, reasons that may be tactical and strategic, given the power of the technoscientific industry.

*Received 12 August 2019; accepted for publication 18 December 2019.*

### LITERATURE CITED

Abu-Saad, K. 2016. Indigenous data matter: Spotlight on Negev Bedouin Arabs. *Lancet* 388:1,983–1,984.

Agrawal, A. 2002. Indigenous knowledge and the politics of classification. *Int. Soc. Sci. J.* 54:287–297.

Anderson, I., B. Robson, M. Connolly et al. 2016. Indigenous and tribal peoples' health (the *Lancet*-Lowitja Institute Global Collaboration): A population study. *Lancet* 388:131–157.

Archibald, J., R. Barnhardt, G. A. Cajete et al. 2008. The work of Angayuqaq Oscar Kawagley. *Cult. Sci. Educ.* 2:11–17.

Berman, S. 1971. *Prejudices and Antipathies: A Tract on the LC Subject Heads Concerning People*. Metuchen, NJ: Scarecrow Press.

Blondel, V. D., J.-L. Guillaume, R. Lambiotte et al. 2008. Fast unfolding of communities in large networks. *J. Stat. Mech.* 10:P10008.

Browne, Simone. 2015. *Dark Matters: On the Surveillance of*

*Blackness.* Durham, NC: Duke University Press.

Cajete, G. 2000. *Native Science: Natural Laws of Interdependence*. Santa Fe, NM: Clear Light.

Carlson, B. 2019. Disrupting the master narrative: Indigenous people and tweeting colonial history. *Griffith Rev*. 64:224–234.

Carroll, S. R., D. Rodriguez-Lonebear, and A. Martinez. 2019. Indigenous data governance: Strategies from United States Native Nations. *Data Sci. J.* 18:1–15.

Christen, K. 2015. Tribal archives, traditional knowledge, and local contexts: Why the "s" matters. *J. West. Arch.* 6:1–19.

Christen, K., and J. Anderson. 2019. Toward slow archives. *Arch. Sci.* 19:87–116.

Cooper, D., T. Ball, M. N. Boyer-Kelly et al. 2019. When research is relational: Supporting the research practices of Indigenous studies scholars. *Ithaka S+R*, 11 April. https://sr.ithaka.org/publications/supporting-the-research-practices-of-indigenous-studies-scholars/.

Davis, B., D. Bond, P. Howat et al. 2009. Maternal and neonatal outcomes following diabetes in pregnancy in Far North Queensland, Australia. *Aust. N. Z. J. Obstet. Gynaecol.* 49:393–399.

Dei, G. J. S. 2000. Rethinking the role of Indigenous knowledges in the academy. *Int. J. Inclusive Educ.* 4:111–132.

Doyle, A. 2013. Naming, claiming, and (re)creating: Indigenous knowledge organization at the cultural interface. PhD diss., University of British Columbia.

Duarte, M. E. 2017. *Network Sovereignty: Building the Internet across Indian Country.* Seattle: University of Washington Press.

Gilligan, C. 1982. *In a Different Voice: Psychological Theory and Women's Development*. Cambridge, MA: Harvard University Press.

Hajibayova, L., and W. Buente. 2017. Representation of Indigenous cultures: Considering the Hawaiian hula. *J. Doc.* 73:1,137–1,148.

Haraway, D. 1988. Situated knowledges: The science question in feminism and the privilege of partial perspective. *Fem. Stud.* 14:575–599.

Harry, D. 2011. Biocolonialism and Indigenous knowledge in United Nations discourse. *Griffith L. Rev.* 20:702–728.

Harry, D., and L. M. Kanehe. 2006. Asserting tribal sovereignty over cultural property: Moving towards protection of genetic material and Indigenous knowledge. *Seattle J. Soc. Justice.* 5:27–66.

Kukutai, T., and J. Taylor. 2016. Data sovereignty for Indigenous peoples: Current practices and future needs. In *Indigenous Data Sovereignty: Toward an Agenda*, T. Kukutai and J. Taylor, eds. Canberra: Australian National University Press, 1–22. doi:10.22459/CAEPR38.11.2016.01.

LaPensée, E. 2017. Relationality in Indigenous food and medicine games. *Resilience* 4:191–200.

Lawson, K. L. 2004. Precious fragments: First Nations materials in archives, libraries and museums. Master's thesis, University of British Columbia.

Lee, D. 2011. Indigenous knowledge organization: A study of concepts, terminology, structure and (mostly) Indigenous voices. *Partnership* 6:1–33.

Liboiron, M. 2015. Disaster data, data activism: Grassroots responses to representing Superstorm Sandy. In *Extreme Weather and Global Media*, J. Leyda and D. Negra, eds. New York: Routledge, 144–162.

Liebler, C. 2018. Counting America's first peoples. *Ann. Am. Acad. Pol. Soc. Sci.* 677:180–190.

Liew, A. 2007. Understanding data, information, knowledge and their inter-relationships. *J. Knowl. Manag. Pract*. 8.

Lilley, S. C. 2015. Ka Pō, Ka Ao, Ka Awatea: The interface between epistemology and Māori subject headings. *Cat. Classif. Q*. 53:479–495.

Littletree, S. 2019. Indigenous systems of knowledge at the intersections of the LIS field and academia. Paper presented at the International Indigenous Librarians' Forum 2019, Waipapa Marae, University of Auckland, Auckland, NZ, 5–9 February.

Littletree, S., and C. A. Metoyer. 2015. Knowledge organization from an Indigenous perspective: The Mashantucket Pequot Thesaurus of American Indian Terminology Project. *Cat. Classif. Q*. 53:640–657.

Luka, M. E., and M. Millette. 2018. (Re)Framing big data: Activating situated knowledges and a feminist ethics of care in social media research. *Soc. Media Soc*. 4:1–10.

Marley, T. L. 2019. Indigenous data sovereignty: University institutional review board policies and guidelines and research with American Indian and Alaska Native communities. *Am. Behav. Sci.* 63:722–742.

Meyer, M. A. 2008. Indigenous and authentic: Hawaiian epistemology and the triangulation of meaning. In *Handbook of Critical and Indigenous Methodologies*, N. K. Denzin, Y. S. Lincoln, and L. Tuhiwai Smith, eds. Los Angeles, CA: Sage, 217–232.

Moorcroft, H., and A. Garwood. 1997. *Aboriginal and Torres Strait Islander Thesaurus*. Canberra: National Library of Australia.

Murphy, M. 2014. Abduction, reproduction, and postcolonial infrastructures of data. *Schol. Fem. Online* 13.3–14.1.

Nakata, M. 2007. The cultural interface. *Aust. J. Indig. Educ*. 36:7–14.

Nakata, M., A. Byrne, V. Nakata et al. 2005. Indigenous knowledge, the library and information service sector,

and protocols. *Aust. Acad. Res. Libr.* 36:7–21.

Ngulube, P., and O. B. Onyancha. 2011. What's in a name? Using informetric techniques to conceptualize the knowledge of traditional and Indigenous communities. *Indilinga* 10:129–152.

Noble, S. 2018. *Algorithms of Oppression: How Search Engines Reinforce Racism.* New York: New York University Press.

Ocholla, D. N., and O. B. Onyancha. 2005. The marginalized knowledge: An informetric analysis of Indigenous knowledge publications (1990–2004). *S. Afr. J. Libr. Inf. Sci*. 71:247–258.

O'Neal, J. R. 2015. "The right to know": Decolonizing Native American archives. *J. West. Arch.* 6:1–17.

Onyancha, O. B., P. Ngulube, J. Maluleka et al. 2018. Towards a uniform terminology for Indigenous knowledge concepts: Informetrics perspectives. *Afr. J. Libr. Arch. Inf. Sci*. 28:155–167.

Page, L., S. Brin, R. Motwani et al. 1998. The PageRank citation ranking: Bringing order to the Web. Technical Report, 29 January. Stanford, CA: Stanford InfoLab.

Pulley, N. A. 2014. Indigetechs: The original time-space traveling Native Americans and our modern world hyper-pow-wow. *West. Hum. Rev.* 68:95–101.

Rainie, S. C., D. Rodriguez-Lonebear, and A. Martinez. 2017. Policy brief: Data governance for Native nation rebuilding (version 2). Native Nations Institute. http://nni.arizona.edu/application/files/8415/0007/5708/Policy_Brief_Data_Governance_for_Native_Nation_Rebuilding_Version_2.pdf.

Ramos, S. C. 2018. Considerations for culturally sensitive traditional ecological knowledge research in wildlife conservation. *Wildl. Soc. Bull*. 42:358–365.

Shannon, C., and W. Weaver. 1963. *The Mathematical Theory of Communications.* Urbana: University of Illinois Press.

Szekely, C. 1997. *Te Ara Tika = Guiding Voices: Māori Opinion on Libraries and Information Needs*. Wellington: New Zealand Library and Information Association; Te Rōpū Whakahau; Māori Library and Information Workers' Association.

Tallbear, K. 2013. *Native American DNA: Tribal Belonging and the False Promise of Genetic Science.* Minneapolis: University of Minnesota Press.

Tsosie, R. 2019. Tribal data governance and informational privacy: Constructing "Indigenous data sovereignty." *Mont. Law Rev.* 80:229–268.

Tuhiwai Smith, L. 2012. *Decolonizing Methodologies: Research and Indigenous Peoples*. 2nd ed. London: Zed Books.

UN Environmental Programme. 1997. Traditional knowledge and biological diversity. Background document to Article 8(j): Traditional Knowledge, Innovation, and Practices, Convention on Biological Diversity, November 24–28 1997, Madrid, Spain. https://www.cbd.int/doc/meetings/tk/wstkbd-01/official/wstkbd-01-02-en.pdf.

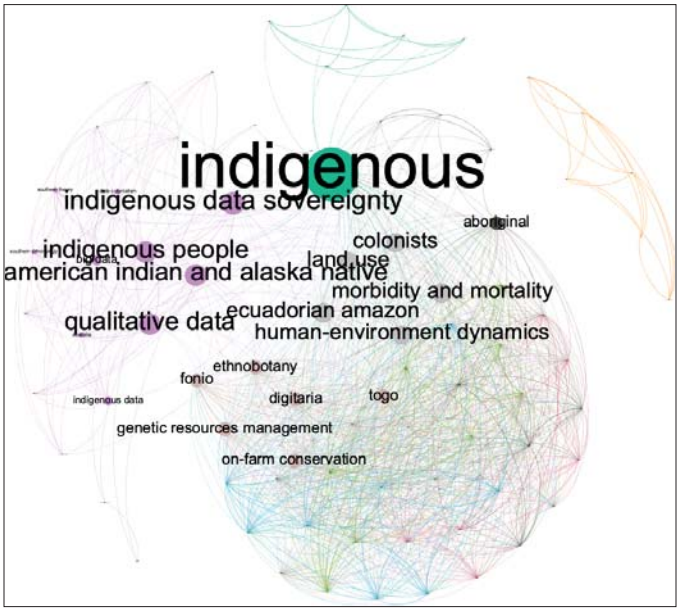
Vigil-Hayes, M., M. E. Duarte, N. D. Parkhurst et al. 2017. #indigenous: Tracking the connective actions of Native American advocates on Twitter. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing, February 2017, Portland, OR, USA*. New York: Association for Computing Machinery, 1387–1399.

Walter, M., and C. Andersen. 2013. *Indigenous Statistics: A Quantitative Research Methodology*. Walnut Creek, CA: Left Coast Press.

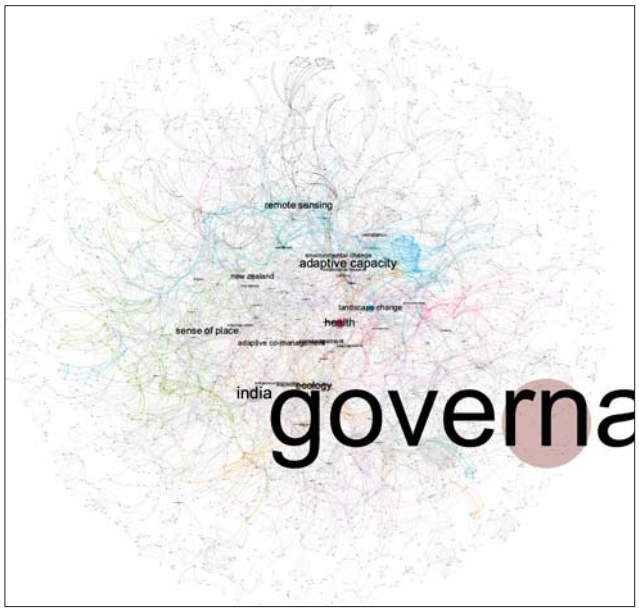
Wilks, J., G. Kennedy, N. Drew et al. 2018. Indigenous data sovereignty in higher education: Towards a decolonised data quality framework. *Aust. Univ. Rev.* 60:4–14.

Wilson, S. 2008. *Research Is Ceremony: Indigenous Research Methods*. Black Point, NS: Fernwood.

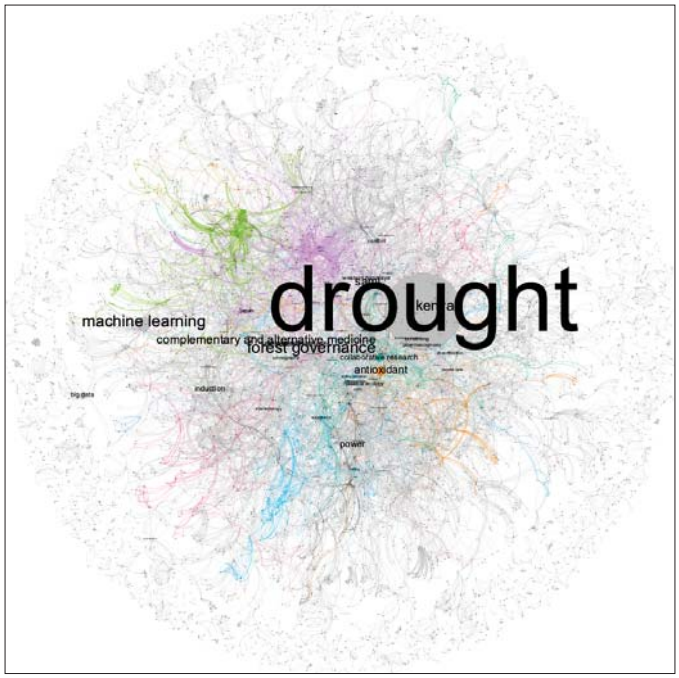
Zins, C. 2007. Conceptual approaches for defining data, information, and knowledge. *J. Am. Soc. Inf. Sci. Technol*. 58:479–493.



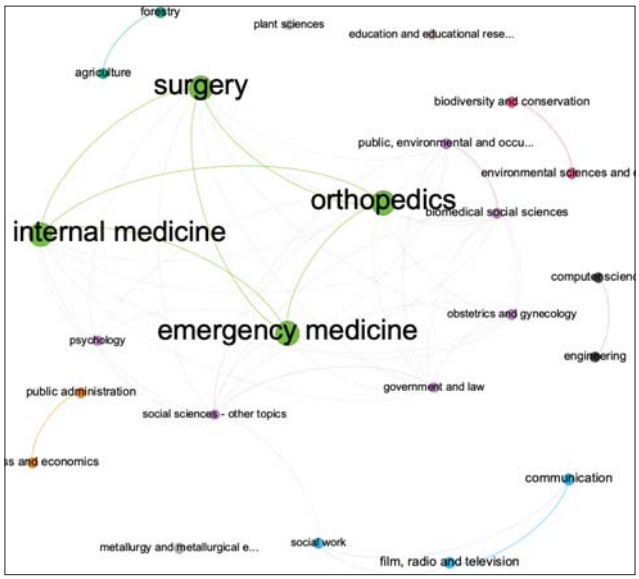

**SUPPLEMENTARY FIGURE S1.** Graph of the author-generated keywords in records containing "Indigenous data."



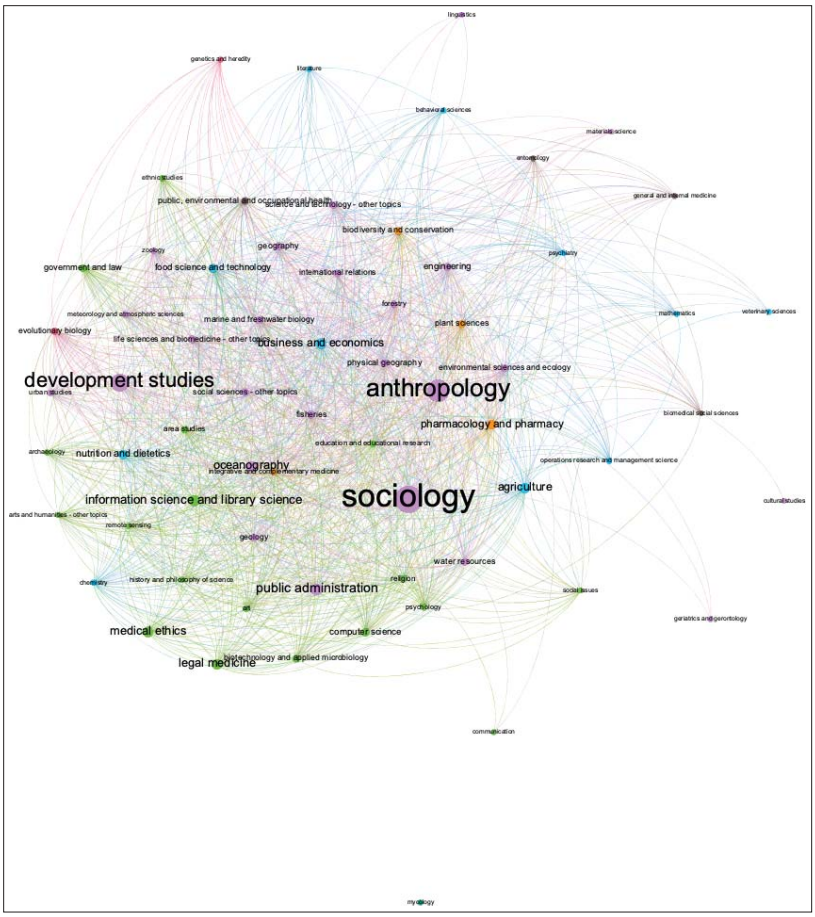

**SUPPLEMENTARY FIGURE S2.** Graph of the author-generated keywords in records containing "traditional environmental knowledge."



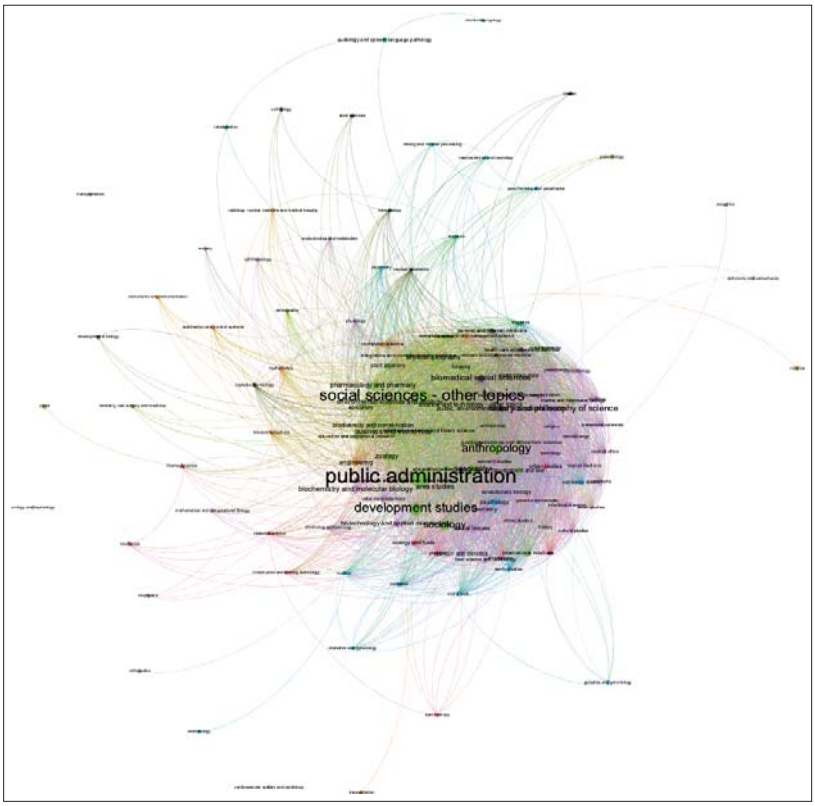

**SUPPLEMENTARY FIGURE S3.** Graph of the author-generated keywords in records containing "traditional knowledge."




**SUPPLEMENTARY FIGURE S4.** Graph of the top research areas that emerged in the bipartite network model between "Indigenous data" and affiliated research areas.




**SUPPLEMENTARY FIGURE S5.** Graph of the top research areas that emerged in the bipartite network model between "traditional ecological knowledge" and affiliated research areas.




**SUPPLEMENTARY FIGURE S6.** Graph of the top research areas that emerged in the bipartite network model between "traditional knowledge" and affiliated research areas.